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Title:	Possibility for Ultra-bright Electron Beam Acceleration in Dielectric Wakefield Accelerators
Author(s):	Simakov, Evgenya I. Carlsten, Bruce E.
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Possibility for Ultra-bright Electron Beam Acceleration in Dielectric Wakefield Accelerators

Evgenya I. Simakov and Bruce E. Carlsten

Los Alamos National Laboratory, Los Alamos, NM 87545

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Outline

- Background and motivation, MaRIE.
- DWAs and energy spread in a witness bunch.
- Conclusion and plans.

Background and motivation, MaRIE

Motivation

• The pre-conceptual design for MaRIE is underway at LANL, with the design of the 12 GeV electron linac being one of the main research goals.

• Requirements the for linac: high gradient and high quality electron beam:

- electron bunch charges of 0.1 to 1 nC;
- normalized rms emittances of 0.1 to 1 mm;
- and rms energy spreads of less than 0.1%.

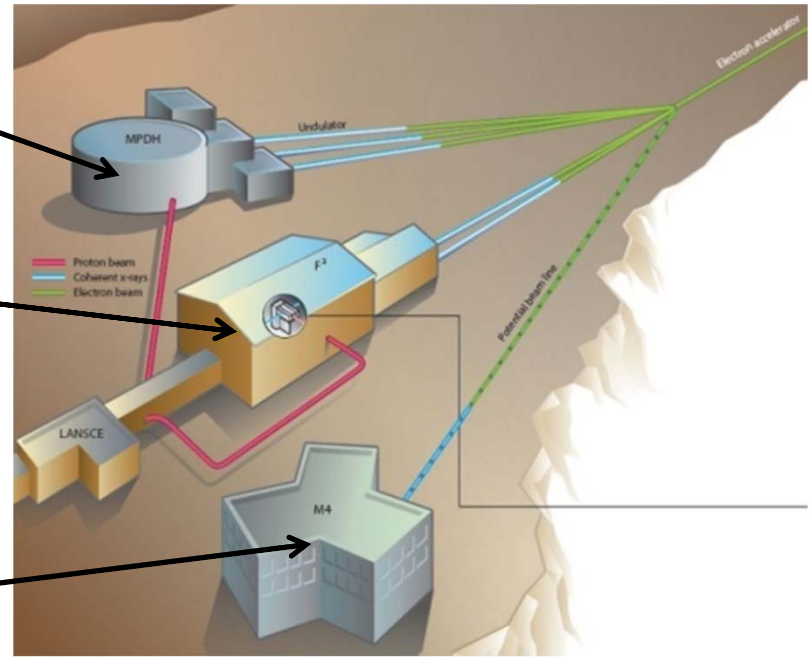
• Exactly the same phenomena, that causes the dominant energy spread effect in beams in conventional linacs can be used to generate extraordinary gradients and small energy spreads in and dielectric structures via wakefield acceleration.

First ideas: Workshop on Application of dielectric wakefield accelerators (DWAs) to next generation X-ray free-electron laser facilities, Argonne National Laboratory, April 20-21, 2011.

MaRIE

The pre-conceptual design for Matter-Radiation Interactions in Extreme (MaRIE) future signature facility is underway at LANL.

- **MPDH**: Multi-Probe Diagnostic Hall. The X-ray scattering capability at high energy and high repetition frequency with simultaneous charged particle dynamic imaging.
- **F^3**: Fission and Fusion Materials Facility. In-situ diagnostics and irradiation environments beyond best planned facilities.
- **M4**: Making, Measuring & Modeling Materials Facility. Comprehensive, integrated resource for materials synthesis and control, with national security infrastructure .



MaRIE requirements on the photons and FEL beam

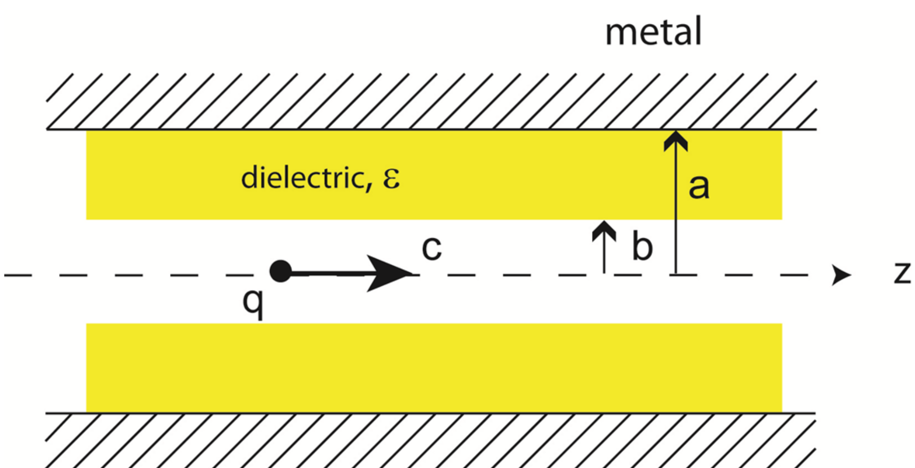
	MPDH	FFF		M4	
Design energy is normally top of range (keV)	5-42 (122)	~10 to >50	10 to 400	0.1 to 1.5	10 to 42
Photons per image	~10^{10}	10^{11}	10^{9}	10^{9}	~10^{10}
Time scale for single image	<1 ps	>1 s	0.001 s	10-500 fs	50 fs
Energy Bandwidth (ΔE/E)	10^{-4} to $<10^{-5}$	10^{-4}	$3x10^{-3}$	10^{-4}	10^{-4}
# of closely spaced bunches within a fixed temporal window	30/1.5 microsec	1 ms	1 ms	Not specified	Not specified
Minimum pulse separation (ps)	350	Not specified	Not specified	Not specified	Not specified
Multiple pulse rep. rate/duration	60 Hz/day; 1 shot/day	0.01 Hz/mo.	1 Hz/month 1 kHz / 5 sec 0.02 Hz / day	1 KHz/day	10 Hz/day; 1 Hz over several days
Polarization	Linear	linear	no	Linear/circular	linear
Tunability in energy (ΔE/E per unit time)	2%/pulse	fixed	5% in 2 µs	10%/s	Factor of 5 over a day
Expected typical spot diameter(s) at target (microns)	1 to 100	100	1 to 10000	0.1 to 10	0.1 to 10
Simultaneous radiation probes in use at one time and what types (i.e. XFEL and incoherent insertion device - ID)	1 XFEL	1 XFEL	1 ID	1 XFEL	1XFEL, 2 ID
Number of hutches (H) (each H is fed by a beamline), total end station (ES) how many of the total ES are available (A) for general flexible use as opposed to dedicated operation	1H, 3ES, 2A	2H,3ES,0A		1H, 1ES, 1A	

DWAs and energy spread in a witness bunch

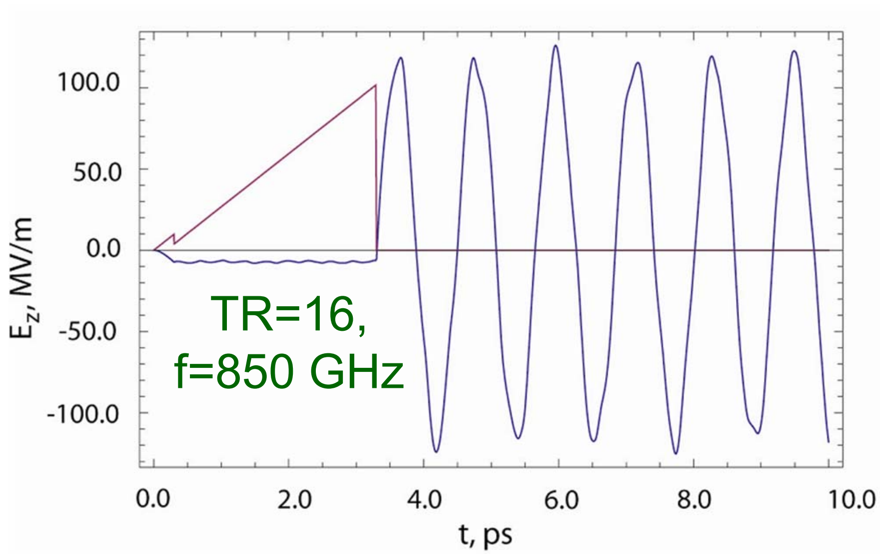
DWAs and high transformer ratios

By shaping the drive electron beam in a DWA into a double-triangular shape one may achieve high transformer ratios, way higher than TR=2, which is the limit for the Gaussian-shaped beam.

A schematic of the dielectric wakefield accelerator

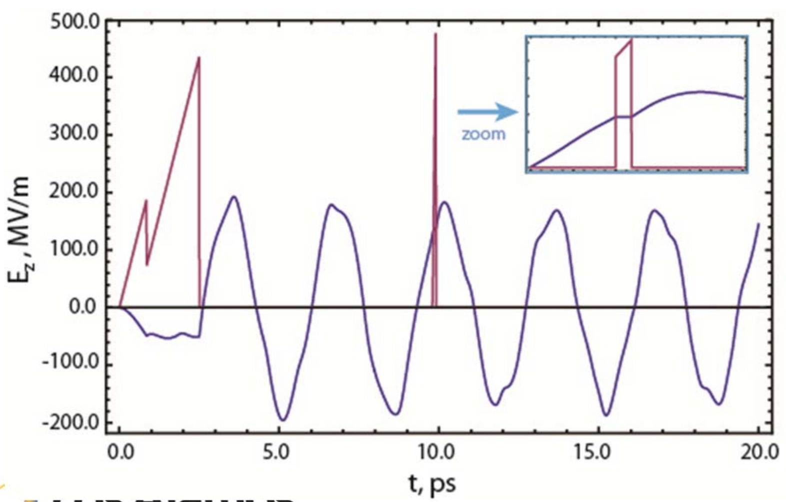


High transformer ratio wakes excited by double-triangular beams in DWAs



Minimization of the energy spread in a witness bunch

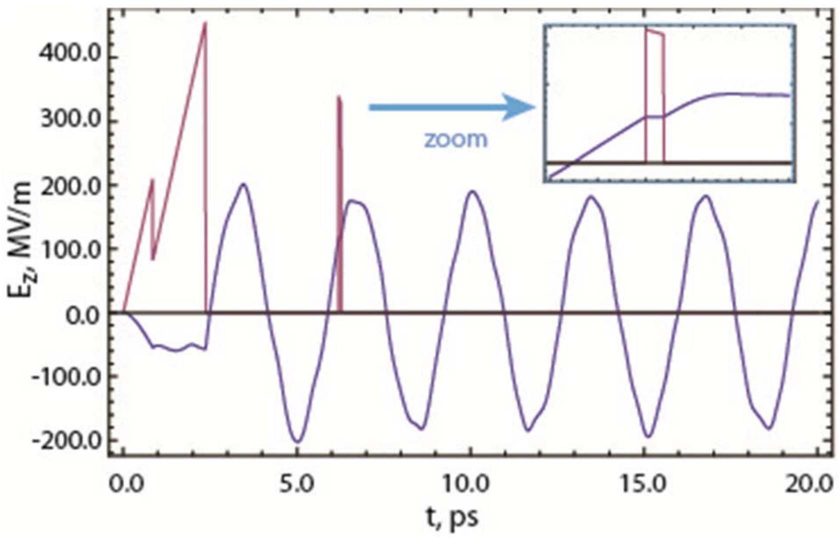
By additionally customizing the shape of the main bunch we designed the configuration which minimizes the wakefield-induced energy spread in the main bunch. The energy spread may be made as low as 0.001%.



Beam pipe OD, *2b*	1.14 mm
Dielectric tube OD, *2a*	1.24 mm
Waveguide cutoff	298 GHz
Charge of the drive bunch	5 nC
Length of the drive bunch	2.127 ps
Charge of the witness bunch	250 pC
Length of the witness bunch	75 fs
Time between the bunches	9.4 ps
Transformer ratio	3.16
ΔG/G	$1.5*10^{-5}$

Minimization of the energy spread in a witness bunch (configuration 2)

Minimization of the energy spread may be achieved in different configurations.



Beam pipe OD, *2b*	1.14 mm
Dielectric tube OD, *2a*	1.24 mm
Waveguide cutoff	298 GHz
Charge of the drive bunch	5 nC
Length of the drive bunch	2.373 ps
Charge of the witness bunch	250 pC
Length of the witness bunch	75 fs
Time between the bunches	6.2 ps
Transformer ratio	3.34
ΔG/G	8.5×10^{-6}

Tolerances

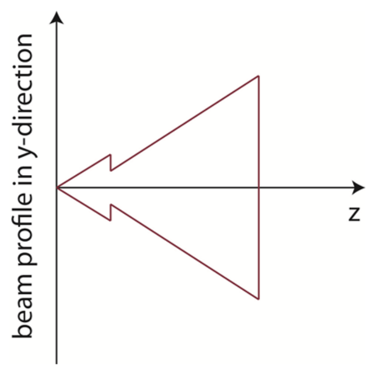
To achieve the low wakefield-induced energy spread the parameters of both, the drive and the main bunches, must adhere to very tight tolerances. For $\Delta G/G<0.01\%$ we must have:

4.999 nC < drive charge < 5.004 nC
249.9 pC < witness charge < 250.1 pC
2.1272 ps < length of the drive bunch < 2.1277 ps
9.3995 ps < time between the bunches < 9.4013 ps
74.95 fs < length of the witness bunch < 75.02 fs

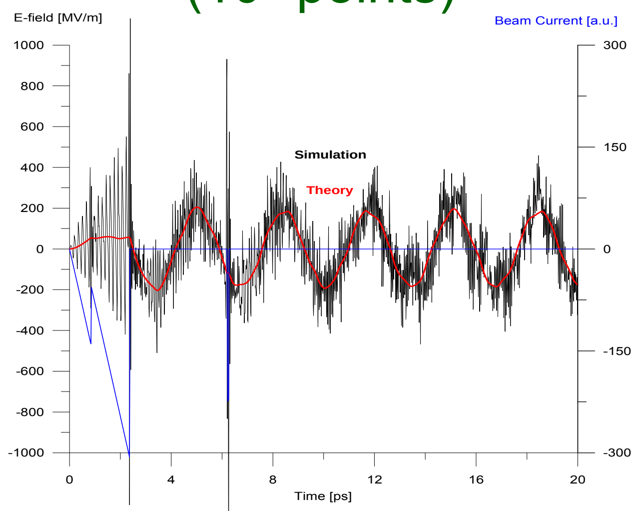
Simulation of triangular bunches

Double-triangular bunches produced by the EEX technique have complicated 3D distributions of charge. Full 3D simulations are needed to compute the excited wakes and understand if small energy spreads are still the case. These simulations are challenging.

Beam profile



Simulation with Particle Studio (10^7 points)



Conclusion and plans

Current plans

We have an active proposal with LANL LDRD to experimentally demonstrate a high-brightness DWA with an acceleration gradient above 100 MV/m and less than 0.1% induced energy spread in the accelerated beam.

- The experiment will be conducted at the New Muon Laboratory at Fermilab.

- In the planned experiment we expect to demonstrate
  - simultaneous generation of a drive bunch and main beam with EEX,
  - significant increases in a DWA transformer ratio, and
  - significant decreases in the measured energy spread from a main beam accelerated through a wakefield process.

Conclusion: Impact for MaRIE

- An 8.8-GeV DWA afterburner for the MaRIE upgrade will boost the energy of the electron beam from 12 GeV to 20.8 GeV.
- With the current 12 GeV MaRIE linac design, generation of the third harmonic (126 keV) photons is suppressed in the wiggler.
- Photon energy above 120 keV is required for the K-shell ionization of uranium and other actinides, an important MaRIE mission and part of its funding justification.
- The DWA afterburner upgrade would allow an order of magnitude greater production of 126-keV photons.